Air Force Electronic Warfare Evaluation Simulator (AFEWES) Infrared Test and Evaluation Capabilities

Hank D. Jackson II*, Tommy L. Blair, Bruce A. Ensor
412 EWG/OL-AB (AFEWES), MZ-1100, AF Plant 4, Box 371, Ft Worth, TX, USA 76101-0371

ABSTRACT

The Air Force Electronic Warfare Evaluation Simulator (AFEWES) infrared countermeasures (IRCM) test facility currently has the ability to simulate a complete IRCM test environment, including IR missiles in flight, aircraft in flight, and various IR countermeasures including maneuvers, point-source flares, and lamp- and LASER-based jammer systems. The simulations of IR missiles in flight include missile seeker hardware mounted on a six degree-of-freedom flight simulation table. This paper will focus on recent developments and upgrades to the AFEWES IR capability. In particular, current developments in IR scene generation/projection and efforts to optically combine the IR image produced by a resistive array with existing foreground lamp sources.

Keywords: Hardware-In-The-Loop (HITL), AFEWES, Infrared Countermeasures (IRCM), Test & Evaluation, Flares, LASER, Lamp Jammer.

1. BACKGROUND

The U.S. Air Force Electronic Warfare Evaluation Simulator (AFEWES) is a secure, government-owned, contractor-operated electronic warfare test facility located in Fort Worth, Texas, managed by the Air Force Flight Test Center (AFFTC), Edwards Air Force Base, California. Lockheed Martin Aeronautics Company has been the contractor responsible for the facility's development, operation and maintenance since its inception. The AFEWES mission is to perform effectiveness testing of DoD and allied electronic countermeasure techniques to enhance aircraft survivability in combat. This is accomplished by challenging EW systems or concepts in highly realistic, dynamic engagements with radio frequency (RF) and infrared (IR) terminal threat weapon systems. Because it has the ability to evaluate actual electronic warfare (EW) systems and concepts against realistic hardware representations of threat systems, AFEWES is categorized as a hardware-in-the-loop (HITL) simulation. Hardware-in-the-loop facilities, which use real-time software to control threat-representative hardware, constitute an important class of modeling and simulation, referred to as virtual or semi-physical.

The AFEWES IR simulation capability can be operated in two configurations (standard and advanced) depending upon the complexity of the customer test requirements. The standard AFEWES IR simulation capability includes effective simulation of aircraft signatures and point-source expendable IR countermeasures. Xenon arc lamps and/or blackbody IR sources mounted in up to eight 3.5-inch-diameter cylindrical housings provide target representation. A mirror system keeps the high intensity IR sources at the appropriate position in the simulated threat hardware field of view. Missile flyout software and preprogrammed aircraft flight profiles control range closure and the relative motion between the target signature and the simulated threat hardware viewpoint. Realistic threat guidance signals are used to update the scene in real-time to accurately enable the simulated threat hardware guidance commands to drive the outcome of the engagement. The advanced AFEWES IR simulation capability enables effective simulation of extended source target and countermeasures. In the advanced configuration, the point-source simulation sources are optically combined with a 512x512-pixel resistive array based projection system to provide extended source aircraft and expendable signatures.

* hank.jackson.af@dcma.mil; Phone (817) 763-4436, DSN 838-5436; Fax (817) 777-4911; http://afewes.edwards.af.mil; 412 EWG/OL-AB, MZ-1100, AF Plant 4, Box 371, Fort Worth, Texas 76101-0371

Report Documentation Page						Form Approved OMB No. 0704-0188
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.						
1. REPORT DATE **2007**		2. REPORT TYPE				3. DATES COVERED **00-00-2007 to 00-00-2007**
4. TITLE AND SUBTITLE **Air Force Electronic Warfare Evaluation Simulator (AFEWES) Infrared Test and Evaluation Capabilities**						5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)						5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **412 EWG/OL-AB,(AFEWES) MZ-1100, AF Plant 4,Box 371,Fort Worth,TX,76101-0371**						8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)						10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**		

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

2. CURRENT IR EVALUATION CAPABILITY

2.1. Point source IR countermeasures evaluation

AFEWES has extensive IR test resources, which are capable of evaluating point-source expendable countermeasure techniques. IR countermeasure tests employ realistic hardware representations of IR threat systems, hosted on a six degree-of-freedom, nine-axis flight motion table. These threats are integrated with dynamic, threat-representative real time digital flyout models. The customer, to maximize effectiveness, can optimize IR flare dispenser timing, sequencing, location and orientation on the host aircraft. For evaluation of effectiveness against two-color systems, AFEWES has an integrated color ratio filter system to enable flares and target representation to contain the appropriate amount of energy in each spectral region of interest. For details related to specific threat-representative hardware available at AFEWES or for test planning, please contact the authors at the above listed contact information.

2.2. IR jamming systems evaluation

The AFEWES IR test facility standard configuration (Figure 1) can represent both lamp- and LASER-based jamming systems. Lamp jammers are represented by modulating and attenuating an appropriately placed arc lamp. Representation of LASER jammers is accomplished by the employment of either the actual multi-band LASER system under test or a surrogate IR LASER. The LASER is mounted on an optics table located above the 72-inch collimating mirror. The beam is split, expanded, conditioned and attenuated to represent the LASER jamming turret(s) mounted on an aircraft. In order to focus the proper amount of IR energy onto the mounted simulated threat hardware optics, the LASER may be attenuated to take into account atmospheric losses, scintillation, and pointing inaccuracies induced by jitter, wing flexure, or turret pointing error. In addition, single or multiple LASER turret installations may be represented and effectively used to optimize the LASER turret(s) placement on the host airframe. One of the primary benefits of this approach is that it enables development and verification of jammer waveforms to maximize effectiveness against a broad number of IR threat systems.

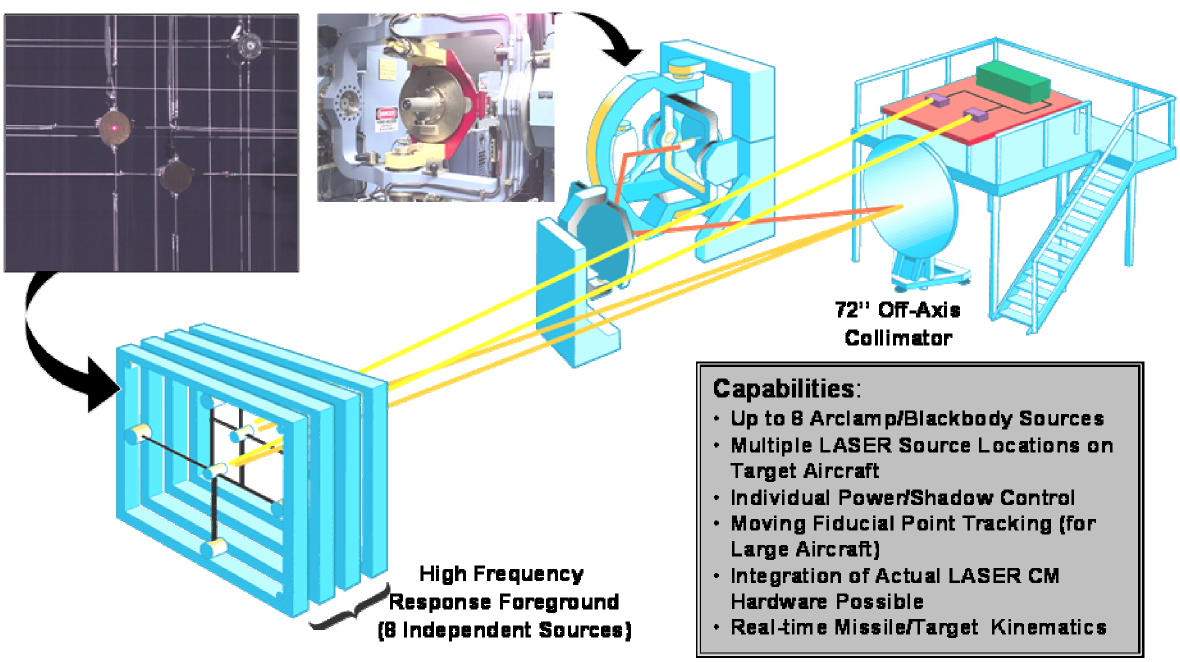

Figure 1. Dynamic LASER Test Capability

2.3. Extended source target and countermeasures representation

With advances in missile and IRCM technology, AFEWES recognized the need to generate more complex target and background scenes.

To meet this challenge, AFEWES has completed the integration and verification of the IR Scene Projection (IRSP) project bringing the IRSP to an Initial Operational Capability (IOC). The IRSP combined the existing AFEWES IR Simulator with products from three discrete sub-projects to develop an improved IR capability. The three sub-projects were: 1) resistive array, 2) optical beam combiner, and 3) scene generation. The resistive array project procured 512x512-pixel wideband IR Scene Projector (WISP) arrays and associated electronics. The resistive arrays were designed and manufactured by Honeywell. The arrays operate with a maximum pixel temperature of approximately 600K to 650K with a 180-Hertz frame rate. The Optical Beam Combiner (OBC) project integrated the resistive array-based IR scene into the AFEWES folded optical path. The OBC project included the collimator and pellicle to expand the resistive array image and fold it into the optical path. The OBC included the design and construction of the hardware to mount the optical components to the flight motion table. The PC-based IR Scene Generator (IRSG) project provided dynamic real-time threat frame rates and frame sizes to exercise a system under test (SUT) in a closed-loop, real-time HITL environment. The dynamic scene generator reacts to the simulated IR threat hardware, SUT, and scenario changes to produce a scene based on the unfolding engagement scenario.

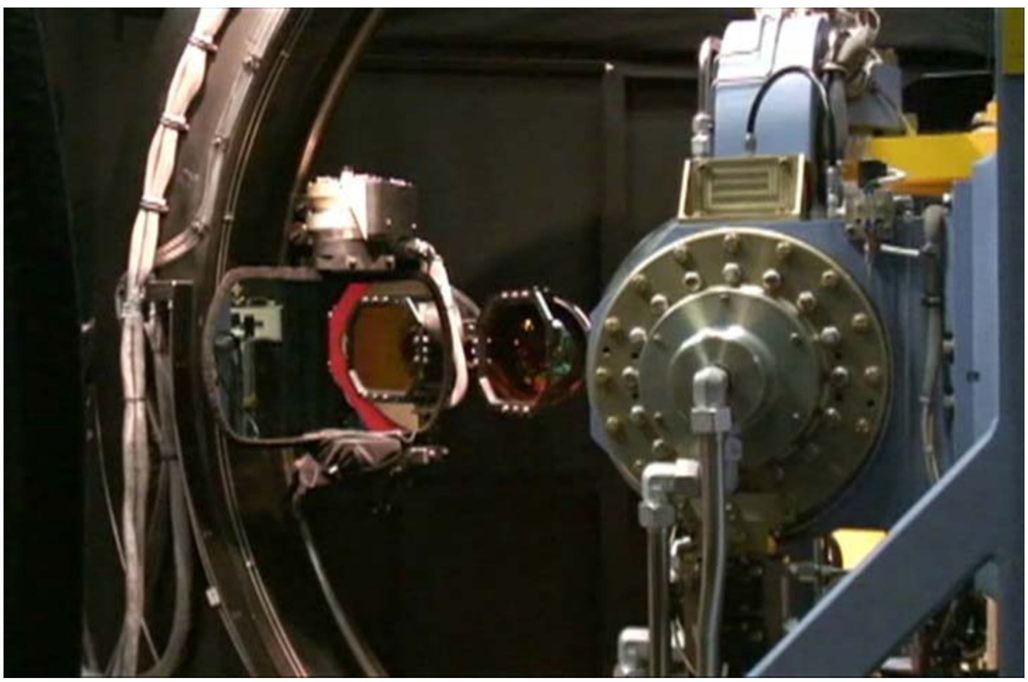

Figure 2. Integrated IRSP Capability.

2.4. Dynamic IR missile testing

Maximum fidelity in IR countermeasures testing requires that the realistic hardware representations of IR threat systems be spun and/or rolled at the appropriate threat rate and that the real-time aerodynamic properties of each threat be represented, as they would in an actual combat engagement. Achieving this in an open-air environment requires firing live missiles directed at fixed target representations attached to a moving trolley on an aerial cable, or surrogate unmanned aircraft. These test approaches are often unable to represent the flight characteristics of the platform of interest. Live-fire is also limited, for reasons of cost and asset availability, to small statistical sample sizes.

AFEWES IR simulations address these technical requirements by integrating realistic hardware representations of IR threat systems with real-time flyout models; spinning and/or rolling each at the appropriate threat rate; incorporating aspect-dependent signature and jammer effects; and averaging 600 to 1,000 launches per week, to produce statistically relevant test databases. In 2002, AFEWES conducted over 9,300 missile engagement simulations in an 11-week period for the Large Aircraft IRCM (LAIRCM) program. In addition to determining jamcode effectiveness, AFEWES predictions were used to enable White Sands Missile Range safety personnel to determine the appropriate footprint for live missile firings at the aerial cable range in support of the LAIRCM program. In 2004, AFEWES conducted over 5,800 missile engagement simulations in a 7-week period, during a Northrop Grumman test sponsored by the Department of Homeland Security (DHS). DHS, in partnership with other federal agencies, is taking an aggressive approach to counter the threat of shoulder-fired missiles against civilian commercial aviation. They will determine the viability, economic costs and effectiveness of adapting existing technology from military to commercial aviation use. The objective of the test was to evaluate the use of LASER countermeasures in the defense of designated commercial aircraft. The test evaluated multiple missile systems, launched at different launch ranges and azimuth angles.

2.5. Verification and Validation

AFEWES simulation resources are validated using the 412 Test Wing Verification and Validation (V&V) process (Figure 3), which requires that all models and components contained within the simulation be validated for their intended uses. AFEWES simulations typically include 1) simulator hardware, 2) a missile flyout model, 3) a signal propagation model, 4) target aircraft signature model, 5) aircraft dynamics, and 6) antenna pattern data bases which represent the system under test, the threat radar, and the hostile missile.

The process uses an Office of the Secretary of Defense (OSD) endorsed, Integrated Product Team (IPT) approach, allowing test customers to be intimately involved in all aspects of validation. This approach expedites accreditation and ensures a thorough validation, based on test requirements. Other IPT members include Modeling and Simulation Executive Agents (MSEAs), who provide truth data and approve the validation of individual simulation components, as well as representatives from the Director, Test, Systems Engineering and Evaluation (DTSE&E) Threat Simulator Validation Review Committee (TSVRC), empowered to provide formal OSD approval of the validation effort.

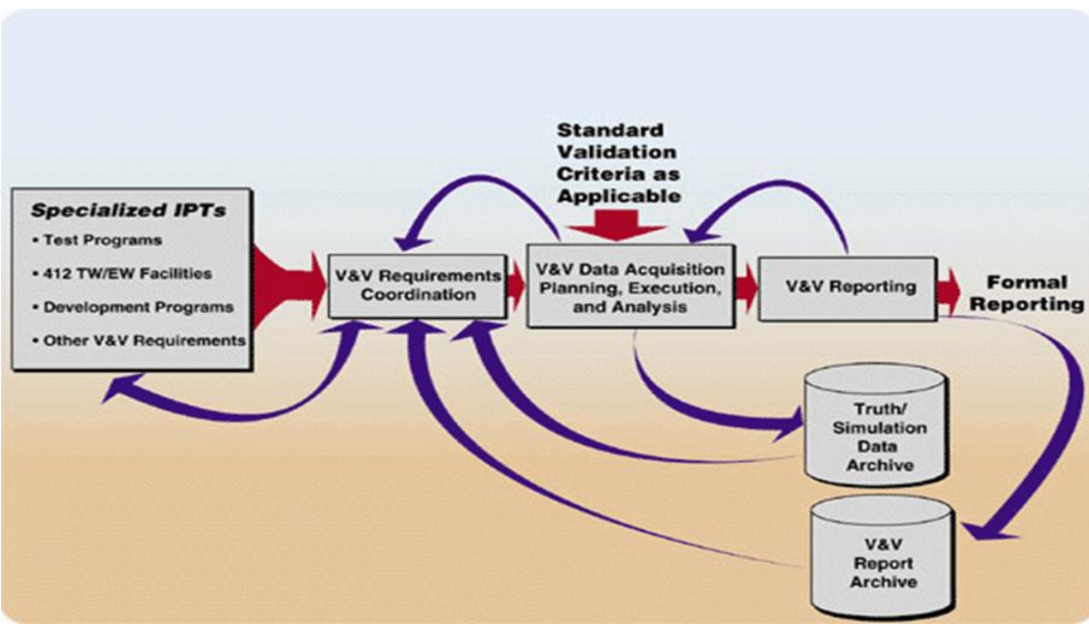

Figure 3. 412 Test Wing Electronic Warfare V&V Process.

Credibility of simulations is the cornerstone of the test process. AFEWES initiated an extensive V&V effort with participation of government experts in the field of IR testing and/or development (totaling over 30 organizations). Although V&V is a continuous effort, significant progress has been made. Referencing Figure 1, all components shown (minus the hardware representation of IR threat system) are referred to as "common elements." The DoD IPT-derived data collection plan for the common elements was implemented. Data was collected and analyzed to provide the customer with a complete and thorough understanding of the simulation. AFEWES has also established data collection methodology for individual threat representative hardware simulations to verify and validate implementation and performance. When this effort is complete, test customers will be further assured that the simulations are credible and appropriate for the intended use. Further, an effort is ongoing using sensitivity analysis methodology, a technique for determining which simulation factors have significant impacts on the desired measures of performance, to support validation.

2.6. Visualization

AFEWES selected, procured, installed and tested a PC computer-based visualization system to display test runs and data in real-time (Figure 4). It allows pre-test scenario verification, as well as post-test review and evaluation of data (playback). Ultimately, this provides customers a better understanding of test events as they unfold during tests at AFEWES, by being able to visualize what is happening in the simulated engagements. Customers have the opportunity to customize displays, choose variables of interest and record digital displays and movies during active tests. Adding this resource enhances the capability of AFEWES and provides test customers with valuable data and visualizations of simulated threat engagements.

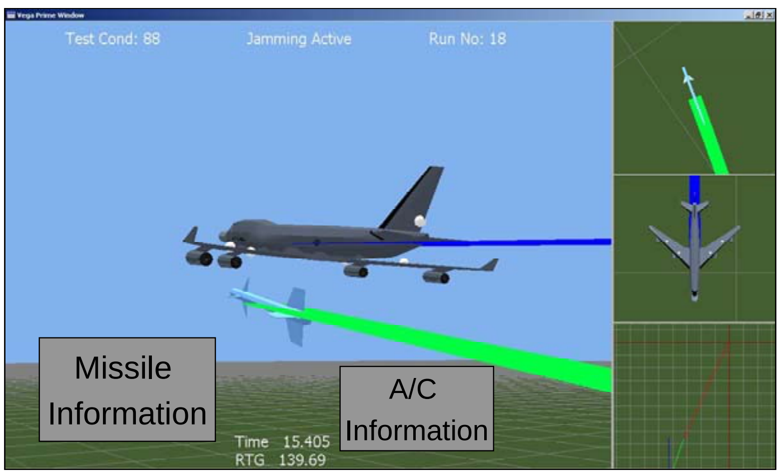

Figure 4. Visualization Sample.

3. DEVELOPING IR EVALUATION CAPABILITY

3.1. IRSP Development History

In 2001, AFEWES contracted, via AFRL/MNGG, to procure 512x512-pixel resistor arrays, used to emit complex scene information. The arrays are wideband IR Scene Projector (WISP) arrays, designed and manufactured by Honeywell. The first array was delivered to AFEWES in February 2003, along with control and interface electronics.

Also in 2001, the Threat Simulator Investment Working Group (TSIWG) funded the 2-year OBC project to determine how to best integrate the resistor array-based IR scene into the AFEWES folded optical path, procure beam-combining hardware and demonstrate a combined complex IR scene in a static environment. Satisfying the TSIWG project requirements involved: specifying and procuring a telescope to expand the image from the resistive array; specifying and procuring a beam combiner; mounting and evaluating the stand-alone and combined IR images from the array and a

blackbody source; and a static demonstration of integrated optics (with pellicle and simulated threat hardware in path) and IR array and control electronics.

In 2002, AFEWES initiated a Small Business Innovative Research (SBIR) proposal to develop a PC-based dynamic real-time IR scene generator to drive a 512X512-pixel array. The Phase I competitive effort was to develop a PC-based, cost effective and highly capable Infrared Scene Generator (IRSG) approach, to simulate real-time, high-fidelity target/countermeasure scenes. The Phase I effort was completed by CG^2 Inc. and Kinetics Inc. and Kinetics was selected for the on-going phase II development. Kinetics delivered the Phase II initial hardware and software in 2005. A Phase II add-on has been added to the Phase II effort extending the completion to 2008. The PC-based IRSG project provides dynamic real-time threat frame rates and frame sizes to exercise a SUT in a closed-loop, real-time HITL environment. The dynamic scene generator reacts to simulated IR threat hardware, SUT, and scenario changes to produce a scene based on the unfolding engagement scenario.

In 2004, AFEWES completed the IRSP Development/Sensitivity Analysis project, partially funded by TSIWG and AFEWES, to determine the sensitivity of simulated IR threat hardware to variations in target scene fidelity using sensitivity analysis. The project included a series of sensitivity analysis based experiments to determine where the simulated IR threat hardware performance for multiple IR threat systems is sensitive to scene generation fidelity, and characterization of the resistive array and optics. In addition, the project included an investigation of the simulated threat hardware's response to targets produced by the IR resistive array.

In 2005, AFEWES completed the IRSP Calibration project, which determined the apparent temperature of the resistive array, the best way to drive the array at maximum rate, and characterized the array update rate.

3.1.1. IRSP Completion Phase I-IV Project

In 2005, AFEWES completed the IRSP Completion Phase I project, which identified the tasks and resources required to complete the IRSP development resulting in IOC.

In 2006, AFEWES completed the IRSP Completion Phase II-IV project, which brought the IRSP capability to IOC. The Final Operational Capability is expected in CY07 with the completion of the IRSP verification and validation. The results from the AFEWES efforts enable an integrated "dynamic" IR resistive array in the AFEWES IR HITL capability.

This advanced approach allows AFEWES to achieve the complexity and dynamic range necessary to evaluate the full spectrum of expendable and active IRCM. The advanced approach mounts the resistor array and optics on the arm extending from the carriage mirror support on the AFEWES flight motion table 5th axis "C-arm." This configuration is illustrated in Figure 5.

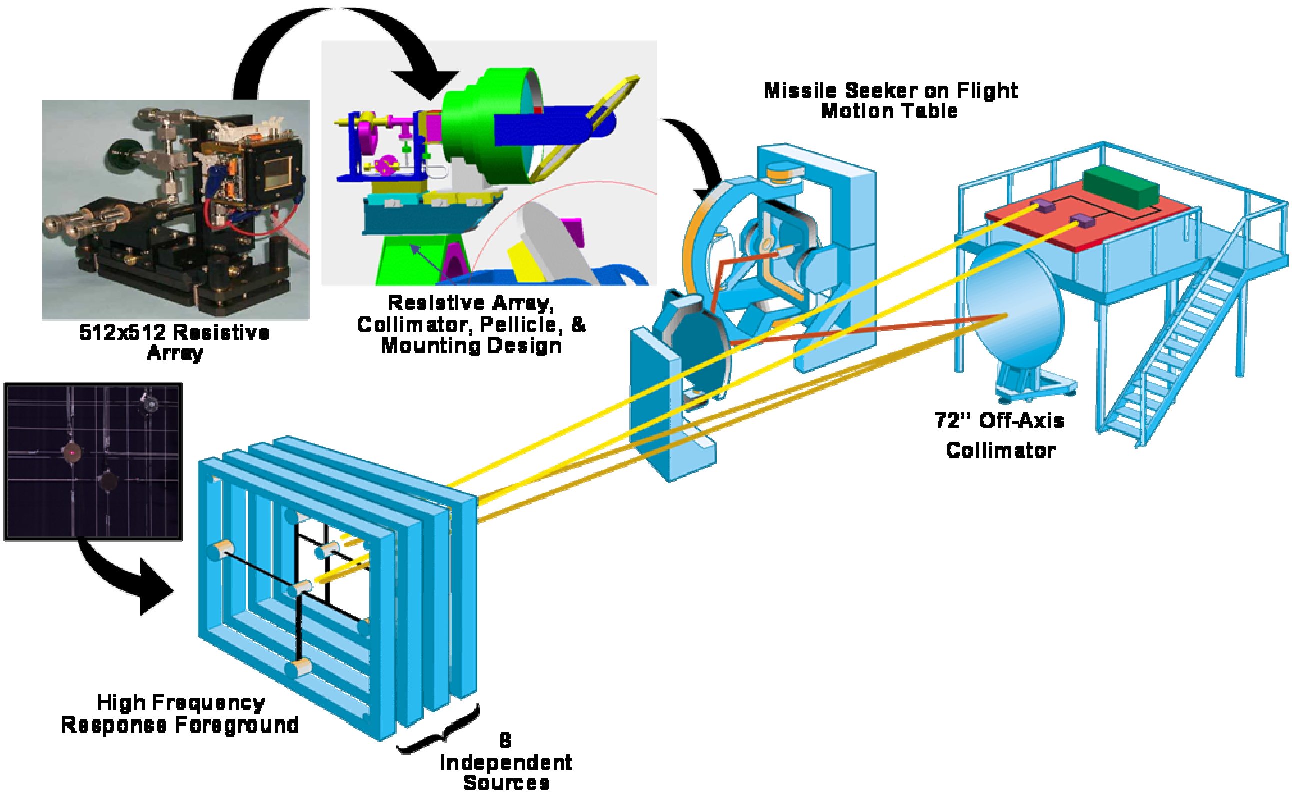

Figure 5. Advanced IR Test Approach.

The IRSP project consists of five phases. Phase's I-IV, which are complete, included the planning, development and verification tasks necessary to bring the IRSP to IOC. IOC is defined as verified dynamic optical combination of simulated aircraft and countermeasures using both the IRSP and IR foreground in the south IR simulator facility. Phase V is funded for 2007 and will include analyses of Phase IV verification test data, additional demonstration runs, and IRSP comparison to field data.

- Phase I: IOC Completion Plan (Complete)
- Phase II: Verification Plan (Complete)
- Phase III: Non-Dedicated Simulator Activities (Complete)
- Phase IV: Dedicated Simulator Activities (Complete)
- IOC
- Phase V: Verification and Validation Activities (Funded)

3.1.1.1. Phase II Verification Plan

In April 2006, AFEWES completed the IRSP verification plan, which identified the steps necessary to ensure the IRSP is functioning properly when statically mounted and when integrated with the existing simulation. The plan also included identification of verification activities already completed or required for each component of the IRSP, mounting, Projector Array Control Electronics (PACE), Analog Interface Electronics (AIE), power, connection, and cooling cables and IR Scene Generation (IRSG). The integrated system verification included verification of dynamic combined scene simulation using the IRSP, foreground and laser table. The combined scene simulation included the following applications and Laser countermeasure simulation.

- Dynamic simulation of an aircraft and laser countermeasure using the foreground and, simultaneously, a countermeasure using the IRSP
- Dynamic simulation of an aircraft using the IRSP, with the aircraft signature augmented by the foreground and the laser countermeasure provided by the foreground
- Dynamic simulation of an aircraft and countermeasure using the IRSP, with the aircraft signature augmented by the foreground and the laser countermeasure provided by the foreground

3.1.1.2. Phase III Non-Dedicated Simulator Activities

In June 2006, AFEWES completed the IRSP development and integration activities that did not require dedicated simulator time. Phase III consisted of a risk assessment, creation of a Software (SW) Interface Control Document (ICD), SW integration of IRSG allowing real time control (performed in the AFEWES IR emulator) and foreground twist removal. The risk assessment focused on the predicted hazards to the pellicle, collimator and resistive array during normal operating conditions when mounted onto the Flight Motion Table (FMT). AFEWES incorporated the risk assessment results into the existing AFEWES IRSP Risk Management Plan. The SW ICD consisted of a command list to control the IRSP via the IRSG PC and the AFEWES master simulator PC. The software integration of the IRSG allows real-time control of the position and orientation of a model. AFEWES performed the software development and integration in the AFEWES IR emulator, which is a digital emulation of the AFEWES simulator computer inputs and outputs. The foreground twist removal activities were necessary to correct the (periscopic rotation) optical twist due to the AFEWES folded path. This foreground twist removal was necessary to ensure optical alignment of energy from the foreground and IRSP.

3.1.1.3. Phase IV Dedicated Simulator Activities

In December 2006, the dedicated simulator activities were completed. The Phase IV activities include the following.

- IRSP Armature and Optical Assembly Stability Verification
- Flight Motion Table Load Verification
- Software Integration of IRSG Allowing Real Time Control
- Static On-Axis Test Verification of Foreground and IRSP
- Dynamic Test Verification of Optical Registration
- IRSP Dynamic Simulation Verification Test
- IRSP and Foreground Dynamic Simulation Verification Test
- Combined Signature Dynamic Simulation Verification Test
- System Demonstration

The IRSP armature and optical assembly stability verification activities subjected each major component of the IRSP (armature, resistive array, collimator and pellicle) to motion tests and verified the optical stability. The tests consisted of step responses or other commands, which represented strenuous simulation conditions. The tests began with benign motion tests and progressed to more stressing scenarios. The motion tests examined the IRSP components incrementally. AFEWES used an IR camera within the FMT inner axes and aligned to the foreground and the IRSP to verify optical stability. The FMT yaw and pitch inner axes were slaved to the outer azimuth and elevation FMT axes. In addition, each increment includes an inspection for changes from its original position and orientation, loosened fasteners, damaged parts and other signs of stress due to motion after each test.

The FMT load verification tests measured the frequency response, velocity step response, and acceleration step response along each set of applicable orthogonal FMT axes with the entire IRSP in place. The tests characterized the new performance of the FMT with the IRSP incorporated for comparison to data from the AFEWES IR common element verification.

The foreground twist removal verification tests collected data to verify elimination of the optical path twist by performing suitable hardware dynamic runs and using an IR camera to measure the twist removal. Figure 6 shows a sample of a five-point crucible image produced with and without the foreground twist correction.

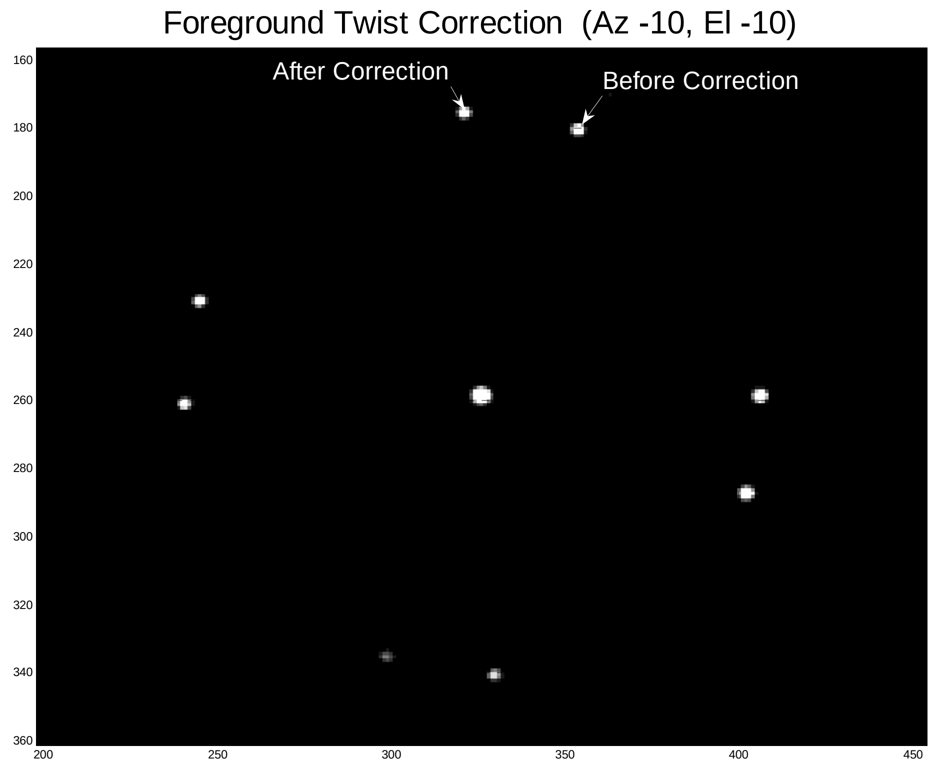

Figure 6. Foreground Twist Correction.

The static optical registration verification tests collected data to verify that identically positioned foreground and IRSP static target positions overlay each other appropriately through the pellicle beam combiner using an IR camera at the FMT center. Figure 7 shows a sample at various ranges of a five-point crucible image produced on both the foreground and IRSP.

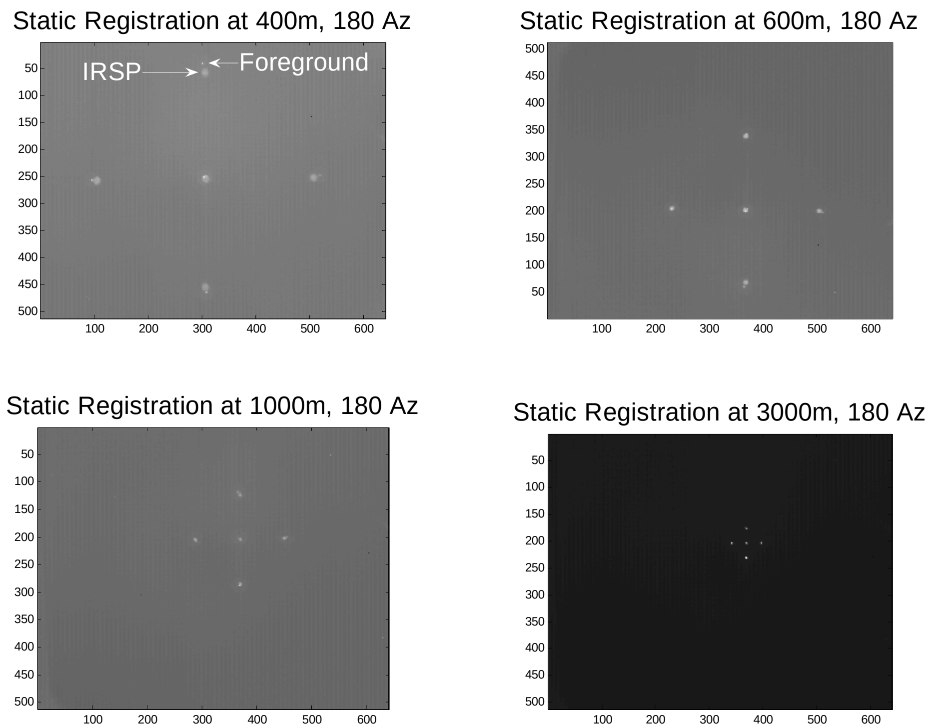

Figure 7. Static Registration Verification Sample.

The dynamic optical registration verification test collected data to verify that identically positioned foreground and IRSP dynamic targets overlay each other appropriately through the pellicle beam combiner during representative test dynamics. These tests were performed with an IR camera installed at the FMT center of motion and with threat representative hardware. These tests verified proper operation of the optical twist and optical registration.

The IRSP dynamic simulation verification test activities verified that a representative image model aircraft (A/C) and countermeasure could be used for closed-loop simulation using the IRSP through the pellicle beam combiner during a threat representative hardware dynamic run. The IRSP and foreground dynamic simulation verification activities verified that the AFEWES foreground sources could simulate an aircraft in conjunction with an area flare projected by the IRSP during a threat representative hardware dynamic run. The combined signature verification test verified optical combination of the IRSP and foreground sources; dynamically simulating an aircraft and multiple IRCM scenarios during a threat representative hardware dynamic run. The tests included simulations with both an area flare and laser jammer. Figure 8 show a sample of the combined signature using both the foreground and IRSP to generate the target aircraft and the IRSP to generate two area flares.

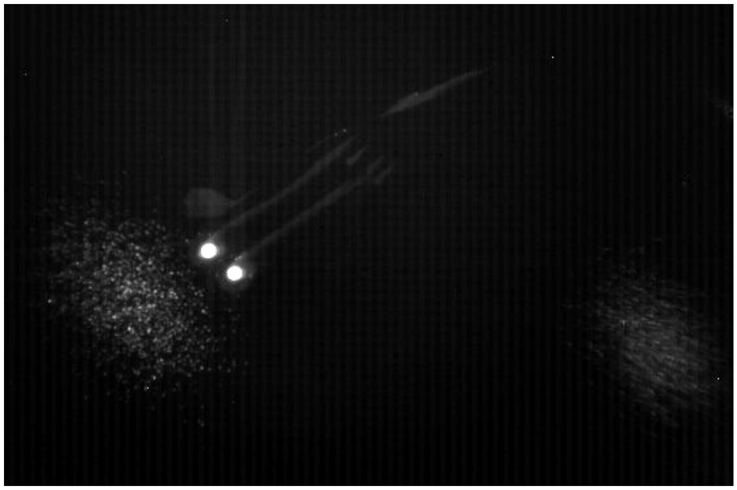

Figure 8. Combined Aircraft Signature and Multiple Area Flares.

The system demonstration executed a three day experimentally designed 80-run test matrix to verify the integrated performance of the IRSP with the existing simulation. The A/C and IRCM simulation methods were varied to examine the impact of various combined scene methods.

3.2. Summary

The IRSP integration, verification testing, and demonstration are complete bringing the capability to IOC. AFEWES has an ongoing task to identify vibration sources, vibration frequency and amplitude, design/develop an isolation mount and verify elimination or reduction of vibration-induced errors. The IRSP project phase V will focus on Verification &Validation in 2007.

4. KEYS TO SUCCESS

AFEWES' ability to provide quick-reaction, secure and cost-effective T&E services has resulted in a multi-national client base, who continue to return to the facility as world events dictate. This fact, combined with a continuing focus on worldwide threat proliferation and emerging EW technology trends, are the principal keys to the facility's long-standing success and ensures AFEWES will continue to provide important contributions to all U.S. military services, allies and industries in the future.

For further information on the established EW T&E capabilities at AFEWES, contact

Hank D. Jackson II
Captain, USAF
Project Manager, 412 EWG/OL-AB
Telephone: (817) 763-4436
Facsimile: (817) 777-4911
E-mail: *hank.jackson.af@dcma.mil*.

Additional information is also available on the Internet at: *http://afewes.edwards.af.mil*.

Further information on the 412th Test Wing, Air Force Flight Test Center, Edwards Air Force Base, California, can be found on the Internet at *http://www.edwards.af.mil/products_svc/index.html*.